Lothar Beyer, Institute of Soil Science, University Kiel

Soil formation in coastal continental Antarctica (Wilkes Land)

BOCKHEIM and UGOLINI (1990) developed general theories of soil formation in Antarctica in dependance of the latitude. However, most soil data from the Antarctic continent were derived from the Dry Valley region close to the Ross Sea, whereas from other ice-free areas no or little pedogenic information is available (PICKARD, 1986; SEPPELT and BRADY, 1988). This changed with the first publication of the Casey area (Wilkes Land) BLUME and BÖLTER (1993). This study suggested, that in terrestrial ecosystems of coastal regions of the Antarctic continent soil formation and chemical weathering occurs to a greater extent as expected in former times (BLUME et al., 1997; 1998). In the present paper we would like to extend the presentation and discussion on soil properties and ecology given by BLUME et al. (1997; 1998) with a proposal of suggested soil formation sequences on a small-scale data base.

The sites and soils are located south of the Australian Casey Station on Bailey Peninsula (Latitude 66°18'S, Longitude 110°32'E) at Wilkes Land in Coastal Continental Antarctica about 700m from the shore. The annual precipitation (180mm) is mostly snow. The mean annual temperature is -9.3°C. During the Antarctic summer of nearly six weeks the temperatures are above the freezing point (e.g. mean in January +0.2°C). Plant communities of mosses, lichens and algae are established (SMITH, 1990).

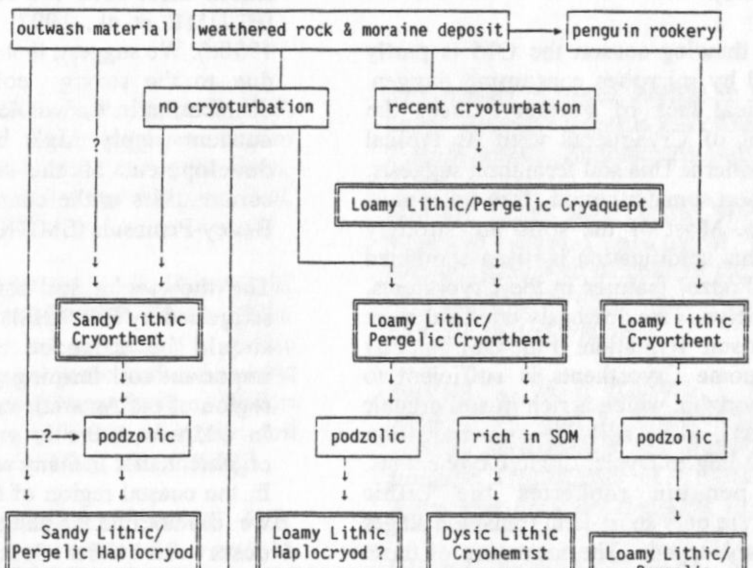

Figure 1. Suggested soil formation in the coastal area of continental Antarctica (Casey Station, Wilkes Land)

The soils were classified according to the recent Keys to Soil Taxonomy (Soil Survey Staff, 1996). Detailed informations concerning the soil formation processes will be discussed by BEYER et al. (1998a).

The parent material in the Casey area is weathered gneiss and shists, moraine deposits and outwash gravels (e.g. PAUL et al., 1995). Because of the new findings at Wilkes Land near Casey Station presented by BLUME et al. (1996, 1997, 1998) and our recent studies a suggested sequence of soil formation in the coastal area of continental Antarctica is given in Figure 1. The Cryorthents are the first step of soil formation due to the accumulation of organics. However, not only the recent vegetation is responsible for the organic matter (OM) input. Until now the origin of the OM is not known exactly (BEYER et al., 1998b), but according to recent knowledge mosses, algae and lichens produce carbohydrates, which are leached into the underlying soil horizon (e.g. MELICK and SEPPELT, 1992; Melick et al., 1994; ROSER et al., 1992). These "left-overs" (BÖLTER, 1993) may stimulate microbial activity, because of the high availability of the organic compounds (BEYER et al, 1997a; BÖLTER, 1991).

During the thawing season the OM is partly decomposed by microbes consuming oxygen. The periodical lack of oxygen induces the development of Cryaquepts with its typical reddish Fe pattern. This soil formation suggests, that in the short summer period, free water must be available. Most of the soils are strongly acidified. This acidification is often combined with initial Podzol features in the Cryorthents. Lithic Haplocryods are obviously one final stage of the recent soil formation. If the OM input by mosses in some Cryorthents is sufficient to form an A-horizon, which is rich in soil organic matter (SOM), these soils become transition segments leading to Dysic, Lithic Cryohemists. On relic penguin rookeries the Lithic Cryorthents are only short-term transition stages to Lithic Haplocryods. The formation of these soils suggests a tremendous OM, Fe and Al translocation from the upper centimeters of soil into the subsoil (BLUME and BÖLTER, 1993; BLUME et al., 1996; BEYER et al., 1997a) and also, that in the thawing period, free water must be available in the soils. In wind-protected depressions and valleys Histosols raise directly on rock. Euic, Lithic Cryofibrists are located at places in the landscape with a high groundwater table or at points with a low topography (BLUME et al., 1997), where meltwater and the leached nutrients are accumulated. The decomposition of OM is reduced due to low temperatures and lack of oxygen (BEYER et al., 1998c). In such a wet Lithic Cryofibrist from algae BEYER et al. (1995) found only a slight decomposition of carbohydrates and little selective preservation of alkylic biomacromolecules. The authors suggest, that due to the extreme climatic conditions and the high water capacity SOM transformation processes are retarded. In higher and more drier positions Dysic, Lithic Cryohemists are placed. In such a Pergelic Cryohemist from mosses BEYER et al. (1997b) found a strong decomposition of hydroxyl and acetal carbon (mainly carbohydrates) and the enrichment of alkyl carbon in the deeper horizons (Figure 2). The data indicate the presence of aromatic humic substances. These moieties do not derive from aromatic initial organic matter (vegetation), because mosses contain no lignin precursors. All Histosols are characterized by high mineral contents (BEYER et al., 1995; 1997b; 1998d; BLUME et al., 1996; 1997), because eolian dust distribution frequently occurs in the coastal area near Casey and Mawson.

Except some very young Lithic Cryorthents at the Løkken moraine close to the permanent ice shield most soils are rich in N, P, K, Mg (BLUME et al., 1997; 1998; BEYER et al., 1998e). We suggest, that this phenomen is also due to the strong eolian mineral matter distribution in the whole landscape. The high nutrient supply might be one reason for the development of the well-developed plant communities in the coastal area of Clark- and Bailey-Peninsula (SMITH, 1990).

The theories of soil formation in Antarctica suggested by BOCKHEIM and UGOLINI (1990) should be extended. Podzolization is an important soil forming process in the coastal region of the Antarctic continent (polar desert). In addition, there is a strong enrichment of organic matter in many soils of the same region. In the coastal region of the Antarctic continent we did not find the ahumic red soils of the cold desert as were described in detail by CAMPBELL and CLARIDGE (1987). The recent data suggest a strong correlation between the soil cover and the vegetation pattern. Nutrient supply in soil is affected by the high availability of K, Mg and P resulting from the input by seabirds and eolian distribution in the whole landscape.

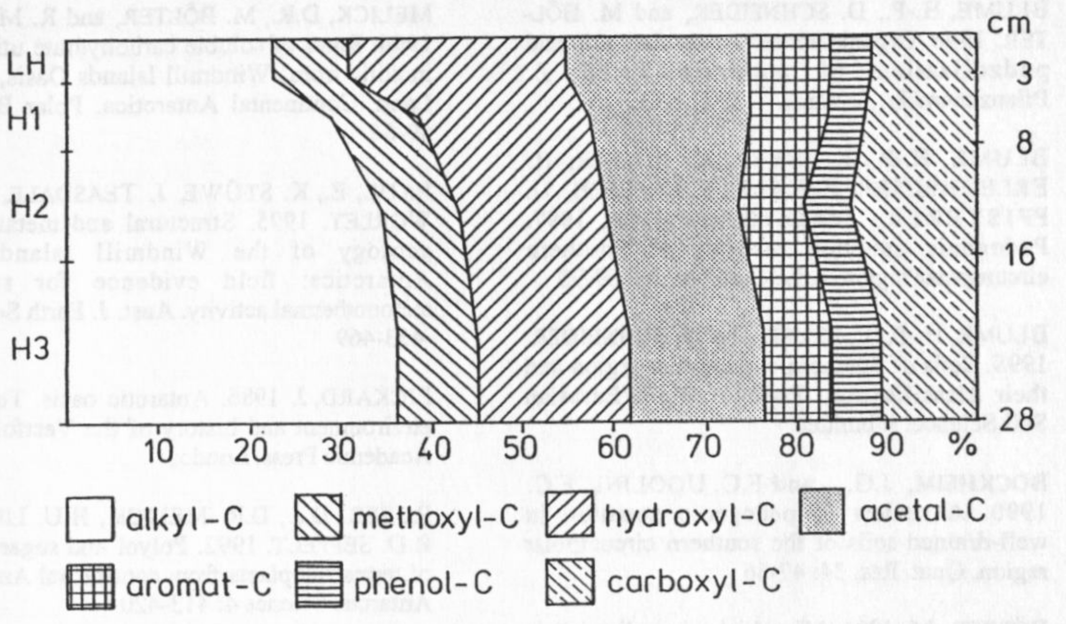

Figure 2: Soil organic matter composition according to the carbon-13 NMR spectroscopy in a peat soil from mosses (Pergelic Cryohemist) near Casey Station (adapted from Beyer et al. (1995)

REFERENCES

BEYER, L., C. SORGE, H.-P. BLUME, H.-R. SCHULTEN. 1995. Soil organic matter composition and transformation in gelic Histosols of coastal continental Antarctica. Soil Biol. Biochem. 27: 1279-1288

BEYER, L., H. KNICKER, H-P. BLUME, M. BÖLTER, B. VOGT, and D. SCHNEIDER. 1997a. Soil organic matter of suggested spodic horizons in relic ornithogenic soils of coastal continental Antarctica (Casey Station, Wilkes Land) in comparison with that of spodic soil horizons in Germany. Soil Sci. 162: 518-527

BEYER, L., H.-P. BLUME, C. SORGE, H.-R. SCHULTEN, H. ERLENKEUSER, and D. SCHNEIDER. 1997b. Humus composition and transformation in a Pergelic Cryohemist of coastal Antarctica. Arctic and Alpine Res. 29: 358-365

BEYER, L., K. PINGPANK, G. WRIEDT, and M. BÖLTER. 1998a. Soil formation in coastal continental Antarctica. Am. Soil Sci. Soc. J. (submitted)

BEYER, L., K. PINGPANK, M. BÖLTER, and R. SEPPELT. 1998b. Small-distance variation of carbon and nitrogen storage in different Antarctic mineral Cryosols near Casey Station. Z. Pflanzenernähr. Bodenk. 161 (sub- mitted)

BEYER, L., M. BÖLTER, R. SEPPELT. 1998c. Thermal regime, microbial biomass and vegetation pattern of soils in the coastal region of Antarctica (Wilkes Land). Arctic and Alpine Res. 30: in preparation

BEYER, L., H.-P. BLUME, C. SORGE, H.-R. SCHULTEN, and H. ERLENKEUSER. 1998d. Humus composition and transformation in a Pergelic Cryofibrist of Coastal Continental Antarctica. Polarforschung 68: submitted

BEYER, L., K. PINGPANK, M. BÖLTER, D. SCHNEIDER, and H.-P. BLUME. 1998e. Variation of carbon and nitrogen storage in soils of coastal continental Antarctica (Wilkes Land). Pochvovedenie/Eurasian Soil Science: in press

BLUME, H.-P., and M. BÖLTER. 1993. Soils of Casey Station (Wilkes Land, Antarctica). p.96-103. *In* D. Gili-chinsky (ed.) Proc. 1st Int. Conf. of Cryopedology, November 1992. Russian Academy of Sciences, Pushchino

BLUME, H.-P., D. SCHNEIDER, and M. BÖLTER. 1996. Organic matter accumulation in and podzolization of antarctic soils. Z. Pflanzenernähr., Bodenk. 159: 411-412

BLUME, H.-P., L. BEYER, M. BÖLTER, H. ERLENHEUSER, E. KALK, S. KNEESCH, U. PFISTERER, and D. SCHNEIDER. 1997. Pedogenic zonation in soils of Southern circumpolar region. Adv. GeoEcol. 30: 69-90

BLUME, H.-P., L. BEYER, and D. SCHNEIDER. 1998. Soils of Southern circumpolar region and their classification. Pochvovedenie/Eurasian Soil Science: submitted

BOCKHEIM, J.G., and F.C. UGOLINI, F.C. 1990. A review of pedogenic zonation in well-drained soils of the southern circumpolar region. Quat. Res. 34: 47-66

BÖLTER, M. 1991. Microbial mineralization in soils and plant material from Antarctica. p.418-422. *In* Proc. Int. Conf. on the Role of the Polar Regions in Global Change, June 1990. University of Fairbanks, Alaska

BÖLTER, M. 1993. Effects of carbohydrates and leucine on growth of bacteria from Antarctic soils (Casey Station, Wilkes Land). Polar Biol.13: 297-306

CAMPBELL, I.B. and G.G.C. CLARIDGE .1987. Antarctica: soils, weathering processes and environment. Elsevier, Amsterdam

MELICK, D.R., and R.D. SEPPELT. 1992. Loss of soluble carbohydrates and changes in freezing points of Antarctic bryophytes after leaching and repeated freeze-thaw cycles. Antarctic Science 4: 399-404

MELICK, D.R., M. BÖLTER, and R. MÖLLER. 1994. Rates of soluble carbohydrate utilization in soils from Windmill Islands Oasis, Wilkes Land, Continental Antarctica. Polar Biol. 14: 59-64

PAUL, E., K. STÜWE, J. TEASDALE, and B. WORLEY. 1995. Structural and metamorphic geology of the Windmill Islands, east Antarctica: field evidence for repeated tectonothermal activity. Aust. J. Earth Sci. 42: 453-469

PICKARD, J. 1986. Antarctic oasis. Terrestrial environment and history of the Vestfold Hills. Academic Press, London

ROSER, D.J., D.R. MELICK, H.U. LING, and R.D. SEPPELT. 1992. Polyol and sugar content of terrestrial plants from continental Antarctica. Antarctic Science 4: 413-420

SEPPELT, R.D and P.A. BRADY. 1988. Antarctic terrestrial ecosystems: The Vestfold Hills in context. p. 177- 184. *In* J.M. Ferris, H.R. Burton, and I.A.E. Bayly (eds.) Biology of the Vestfold Hills, Antarctica. Kluwer Academic Publisher, Dordrecht

SMITH, R.I.L. 1990. Plant community dynamics in Wilkes Land, Antarctica. Proc. NIPR Symp. Polar Biol. 3: 229-244

SOIL SURVEY STAFF. 1996. Keys to Soil Taxonomy. USDA-NRC, Washington. 7th ed

Lothar Beyer
Institute of Soil Science
University Kiel
Olshausenstraße 40
D-24098 Kiel, Germany